LORAN-C MONITOR CORRELATION OVER A 92-MILE BASELINE IN OHIO

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Abstract

Two Loran-C monitors, at Galion and Athens, Ohio, were operated over a one-year period, measuring chain 9960 TD and SNR. Analysis of data concentrated on correlation of short-term TD variations during the winter months of 1985-86, over the 92-nm baseline.

Excellent correlation was found, with slight additional improvement possible if local temperature is also included in the analysis. Although SNR and TD effects were suspected during the presence of thunderstorms near the monitors, the scope of the study did not permit storm-by-storm analysis. This is a necessary area for future work.

A computer tape data base of all measurements was produced, with measurements at both sites included. Data recording and analysis concentrated on the fall and winter months of September 1985 through mid-February 1986.

Background

Following a measurement study [1] to determine the suitability of Loran-C signals at Galion, Ohio, for instrument approach support, a ground monitor was installed to obtain data on signal variations at the site. The monitor consisted of a Northstar 6000 receiver linked to a small computer, driving a digital tape recorder [2]. An uninterruptible power supply was provided after discovery of frequent momentary power outages at the site. Subsequently, a monitor using an ARNAV AVA-1000 receiver was installed at Athens, Ohio, approximately 92 nm south of Galion.

Galion monitor coordinates were determined by theodolite and laser ranger measurement from the runway threshold benchmarks surveyed for the initial study [1]. At Athens, a survey combining trans-located TRANSIT measurements with conventional ground survey techniques was used. Expected TD values were then determined using the FAA Airport Screening Program [3, 4].

Various investigators have measured the long-term seasonal variation and have compared techniques for modeling the observed phenomena [see, for example, 5]. For the work reported here, shorter term

variations were emphasized, while the entire measurement data base was preserved for combination with others data for subsequent analysis as desired.*

Short-period variations may be caused by thunderstorms in the vicinity of the monitor, in which case SNR values fall due to increased local noise. The TD noise then also increases, reducing the reliability of the measure over a period of minutes or hours, but generally retaining the longer term mean value. Variations with weather system movement as the suspected cause occur over a period of hours or days, depending upon weather dynamics. For this study, the Loran-C sample period was extended to one hour by averaging to permit comparison of general weather effects. Raw data plots were inspected for evidence of storm-related variations.

Short-period TD variations are important, although generally smaller than seasonal variations. Refinement of Loran-C instrument approaches in the future through pseudo-differential use of monitor data will require knowledge of these TD movements. Storm-related SNR effects on TD quality are of concern both because of the resulting monitor output TD noise and because the storm is simultaneously affecting the airborne receiver. Differences between monitor and navigation receiver response to the impulse noise could well cause divergent TD values, accentuating position errors.

Data Collection

The two monitors were operated simultaneously during the winter of 1985-86. Each unit was designed to record all TDs and SNR values for Loran-C chain 9960 at approximately one-minute intervals. Tape recording limitations at the Athens site prompted a 5-minute interval for this monitor. Each measurement was time-tagged with date and time to one second. Initial results were reported in graphical form [4, for example], and computer tapes were aggregated into a complete data base for subsequent analysis.

At Galion, some 301,000 observations were recorded, most during the months of August 1985 through mid-February 1986. A subsequent recording session was performed during April 1986 to confirm that TD values had returned to warm-weather values observed in mid-1985.

At Athens, 29,000 measurements were recorded during a period bracketing the Galion monitor's operation.

Data Review

An overview of the data plots shows the anticipated seasonal variations, plus interesting short-term features. Thunderstorms in the Galion local area may have produced SNR reductions in all primary-triad (MYZ) measurements, but time and scope permitted only a partial analysis of these data. These local events were characterized by highly variable SNR in all three

*The tape data were delivered to the DOT Transportation Systems Center, Systems Evaluation Division, Cambridge, MA.

traces, with reductions of as much as -12 dB, lasting generally for 1-2 hours. The TD variations in both M-Y and M-Z were ± 0.25 to ± 0.5 μsec during strong events. Receiver cycle slips did not occur, likely due to the short-pulse nature of the noise. The TD effects were noisy in character, with the mean value remaining at the pre-event position.

Hurricane Gloria, moving up the U. S. east coast in late October 1985, apparently caused selective reduction in the Carolina Beach (Y) trace of up to 6 dB, leaving Dana (Z) and Seneca (M) unaffected.

It is evident from the data that local noise events can cause monitor data variations which would cause no-go approach indications. Such noise may originate with thunderstorms; this was not determined in all cases at Galion. The magnitude of such variation will be dependent upon the characteristics of the monitor receiver used. It is important to determine the effects of this type of interference on the receivers to be used in FAA approach monitors so that output data processing can minimize false no-go indications. If storms are the cause of these events, a single storm near the monitor could shut down approaches over a large area. A mosaic algorithm, using more than one monitor, may be necessary.

Effects of SNR on TD quality were considered for the MYZ triad at Galion (refer again to figure 1, at non-storm periods). The master SNR varied from +5 dB during the day, to +3 dB at night. The M-Z TD, with Dana signals at +5 dB day and +3 dB night, showed variations of generally less than ± 0.1 μsec., even at night, as expected for these high SNR values. No significant day/night bias is evident.

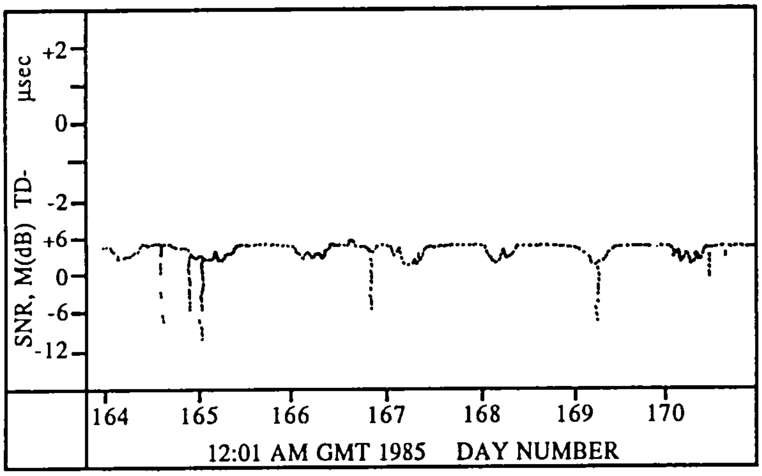
The Carolina Beach (Y) signal varied from +3 dB day to -6 dB night, and the TD varied approximately ± 0.05 μsec day and ± 0.1 μsec night.

These observations indicate TD position noise of less than 100 feet short-term, and are typical of the total observation period. It should be possible to relax the 0 dB SNR requirement for Loran-C approaches once experience is gained with the actual monitor receivers.

Non-primary TDs from Caribou and Nantucket evidenced position variations of from ± 1,200 to 2,400 feet at -12 dB, and of ± 400 feet at -8 dB, respectively. Poor geometry and low SNR combine to disqualify these TDs in Ohio.

Figure 2 shows an example of TD variation with movement of weather systems. This observation led to the temperature correlation discussed in the next section. A TD shift of nearly 0.25 μsec occurred, with the peak variation coincident in time with the passage of a strong cold front (temperature drop of > 30 degrees in approximately 12 hours). The lowest temperature of 20 degrees F occurred at 0000 on day 337. Temperatures then recovered to pre-frontal levels over the next nine days.

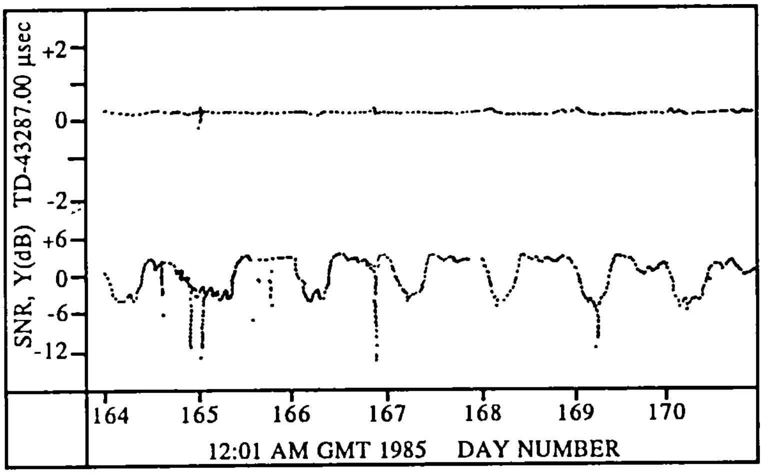
This weather-related effect is most pronounced during the winter and appears to introduce most of the short-to-medium term variation in the signal.



GALION, OH LORAN-C MONITOR
INTERIM DATA FOR 9960 TD M

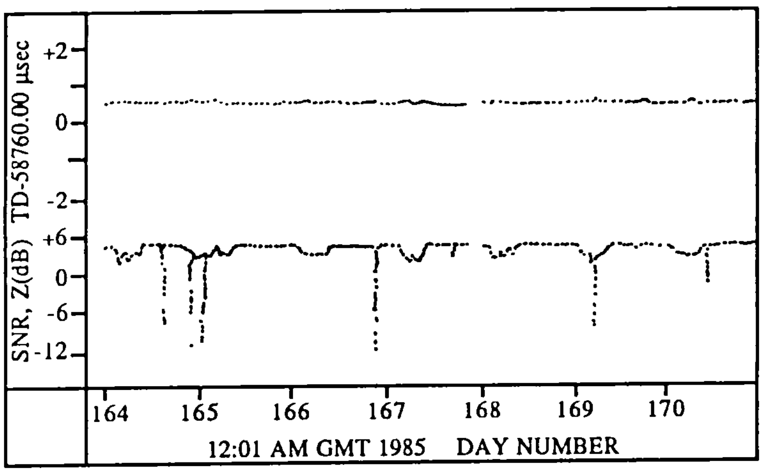
Figure 1a.

Noise and diurnal events; Ohio primary triad.



GALION, OH LORAN-C MONITOR
INTERIM DATA FOR 9960 TD MY

Figure 1b.



GALION, OH LORAN-C MONITOR
INTERIM DATA FOR 9960 TD MZ

Figure 1c.

Correlation of Monitor Data

Some insight into the range of validity of Loran-C monitor data may be obtained from the correlation of Athens and Galion monitors' output. Located 92 nm apart on essentially a north-south line, these two monitors produced highly correlated outputs, as may be seen in general from figure 3. Tables 1 and 2 give the comparisons in more detail.

CORRELATION

X_1 = Galion TD or SNR

X_2 = Athens TD or SNR

X_4 = Athens Temperature

	r_{12}	$r_{12.4}$	$r_{14.2}$
MW	0.952	0.806	0.247
MX	0.954	0.802	0.341
MY	0.954	0.801	0.339
MZ	0.954	0.801	0.337
SNRM	0.954	-	-
SNRW	0.888	-	-
SNRX	0.937	-	-
SNRY	0.950	-	-
SNRZ	0.955	-	-

n = 1072 n - 32

Data is for January 15 through February 16, 1986

Table 1
Correlation and Partial Correlation

REGRESSION

Galion TD =

Athens TD (A) + Athens Temperature (B)

	A	B
MW	0.819	0.153
MX	0.769	0.213
MY	0.769	0.213
MZ	0.769	0.213

MULTIPLE CORRELATION

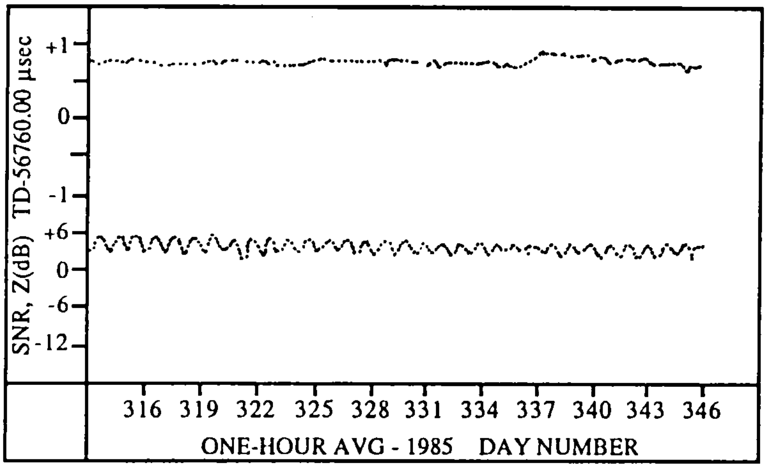
Quality of Prediction Based on Actual Galion TDs

	$R_{1.24}$	$R^2_{1.24}$	r^2_{12}
MW	0.955	0.913	0.906
MX	0.960	0.922	0.910
MY	0.960	0.922	0.910
MZ	0.960	0.922	0.910

Table 2
Regression and Prediction

Figure 3 is a plot of the 1-hour averaged data from Galion and Athens monitors from January 15 through February 16, 1986. The period was chosen to illustrate typical winter-months movement of a TD. A range of nearly 0.5 μsec is seen at both locations.

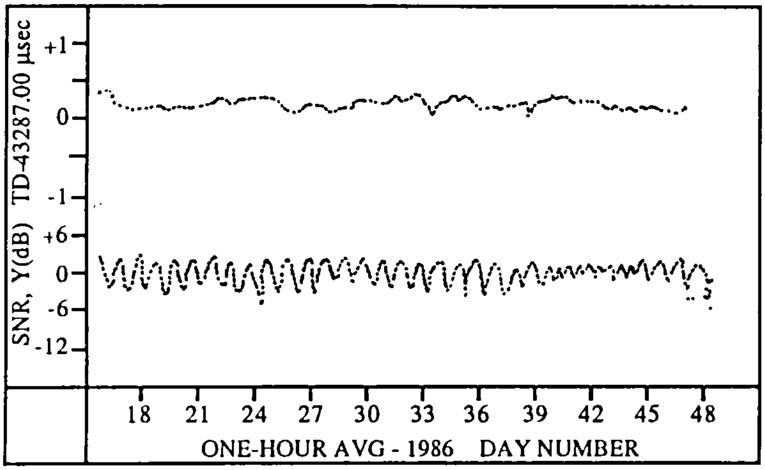
Table 1 shows results of simple correlation between Galion and Athens, on TD and SNR values. As shown, high positive correlation is shown in all cases, with a correlation coefficient r(12) above 0.95 for all TDs. Partial correlations r(12.4) and r(14.2) indicate the degree to which Athens TD and Athens temperature account for variance in Galion TD, with the third variable held constant. These partials are required for computation of the regression coefficients.



GALION, OH LORAN-C MONITOR
INTERIM DATA FOR 9960 TD MZ

Figure 2.

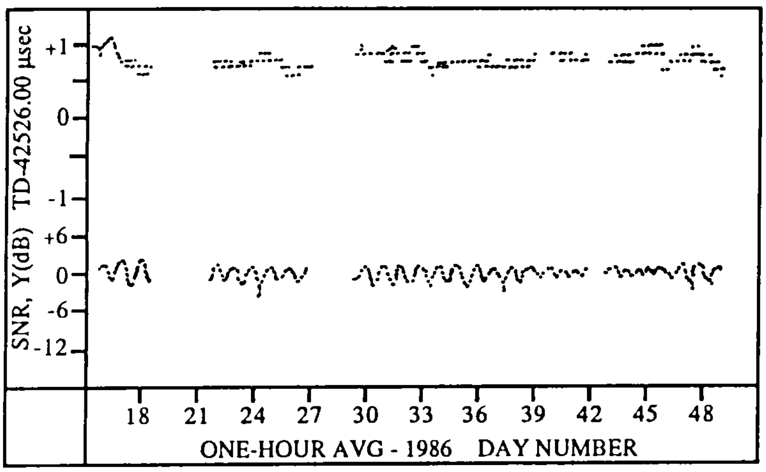
Cold-front passage.
(30° temperature shift)
December 3, 1985.



GALION, OH LORAN-C MONITOR
INTERIM DATA FOR 9960 TD MY

Figure 3a.

January-February data for M-Y, averaged to 1-hour intervals; Galion.



O.U. AIRPORT LORAN-C MONITOR
INTERIM DATA FOR 9960 TD MY

Figure 3b.

January-February data for M-Y, averaged to 1-hour intervals; Athens.

In Table 2, the linear prediction equation is developed. The Galion TD value is predicted from Athens TD and temperature, 92 nm away. Coefficients A and B indicate the weight given to each of the predictor variables. As expected, the Galion TD is much more closely related to the Athens TD than to the Athens temperature as indicated by the high A values and the low values for B.

Table 2 concludes with the multiple correlation, giving an index of quality for the prediction. The predicted TD values from the regression equation are compared with actual Galion data. R(1.24) indicates the coefficient of multiple correlation for each TD using the linear prediction equation A and B values. The square of this coefficient is the coefficient of determination, which can be interpreted as "... for TD M-W, 91.3% of the variation at Galion is accounted for by variations at Athens ...", for example. The degree to which temperature helps the prediction may be shown by the square of r(12), shown in the last column of Table 2. In the M-W case, 90.6% of the Galion variation is accounted for by simple correlation with Athens, ignoring temperature altogether. The result is an improvement of less than one percent when temperature is considered.

The fact that coefficients for M-X, M-Y and M-Z are identical is coincidental and flows from the fact that r(12) was the same in each case.

The data show good correlation over a baseline similar to that which has been proposed for FAA monitors. Note that the correlations performed here use approximately one month's data and thus will not be sensitive to longer term seasonal variations.

Conclusions

Local thunderstorms may have caused receiver-output variations. A single storm could shut down Loran-C approaches over a large area, unless overlapping monitor coverage permits alternate monitor consideration.

The data indicate minimal TD quality derogation with negative SNR as low as -6 dB at a secondary, with high positive SNR at the master. Further consideration to permitting approaches, even with monitor SNR values below zero, is warranted. The TD variations with SNR tend to be zero-mean noise, with minimal day/night bias present.

Over the 92-nm path tested in Ohio, correlation of short-term TD variations is good, and some additional improvement is obtained by including temperature in the computation. The increase is small and does not warrant instrumenting monitors for temperature measurement.

Recommendations

For the primary triad in Ohio, TD data show few ill effects of SNR as low as -6 dB. Consideration should be given to relaxation of the 0 dB monitor SNR requirement for Loran-C instrument approach initiation.

While TD data show excellent correlation over the 90-mile baseline, it should be noted that the north-south orientation may contribute to this positive correlation, since both monitors are affected by typical weather patterns at nearly the same times. A similar east-west baseline distance should be similarly measured and analyzed.

If weather effects are to be measured in subsequent tests, consideration should be given to humidity as a variable, rather than temperature. Also, this measurement should be automated and recorded at intervals similar to the Loran-C samples.

Specific measurements should be carried out to characterize short-term monitor effects caused by thunderstorm activity. Ground-based Stormscope and NWS weather radar data could be used as independent-variable measures.

References

[1] Lilley, R. W. and Brooks, N. K., "Evaluation of Loran-C for Instrument Approaches in Ohio," Proceedings of the WGA, Technical Symposium, October 1984, WGA, Bedford, MA.

[2] Edwards, J. S., "Loran-C Monitor Technical Manual," Technical Memorandum J-2, Avionics Engineering Center, Ohio University, May, 1985.

[3] El-Arini, M. B., "Airport Screening Model for Nonprecision Approaches Using LORAN-C Navigation," Report No. MTR-83W180, The MITRE Corporation, McLean, VA, May 1984.

[4] Lilley, R. W. and McCall, D. L., "Operational Considerations for Loran-C in the Non-Precision Approach Phase of Flight," Proceedings of the WGA, Fourteenth Annual Convention, October 1985, WGA, Bedford, MA.

[5] McCullough, J., et al., "A First Look at Loran-C Calibration Data in the Gulf of Mexico,", Woods Hole Oceanographic Institution, Woods Hole, MA.

Acknowledgements

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